# Magnetic Stripe (Magstripe) Technology – In Detail

The point of this FAQ document is to provide some more detailed information regarding magstripe cards. This is mostly for the extremely curious or technically-oriented, propeller head types.

Much of this technical info comes from a 1991 article, written and posted on the Internet by a person known only as "Count Zero." Thanks a bunch, Count, for much of the information upon which this article is based.

## The Basics

Ferromagnetic materials are substances that retain magnetism after an external magnetizing field is removed. This principle is the basis of all magnetic recording and playback. Magnetic poles always occur in pairs within magnetized material, and magnetic flux lines emerge from the north pole and terminate at the south. The elemental parts of magstripes are ferromagnetic particles about 20 millionths of an inch long, each of which acts like a tiny bar magnet. These particles are rigidly held together by a resin binder. When making the magstripe media, the elemental magnetic particles are aligned with their north-south axes parallel to the magnetic stripe by means of external magnetic fields, while the binder material hardens.

These particles are actually permanent bar magnets with two stable polarities. If a magnetic particle is placed in a strong external magnetic field of the opposite polarity, it will flip its own polarity. (That is, north becomes south and south becomes north.) The external magnetic field strength required to produce this flip is called the coercive force, or coercivity of the particle.

Magnetic pigments (materials that the stripes are made from) are available in a variety of coercivities. This will be addressed in more detail at the conclusion of this document.

An unencoded magstripe is actually a series of north-south magnetic domains. The adjacent N-S fluxes merge and the entire stripe acts as a single bar magnet with north and south poles at its ends.

However, if a S-S interface is created somewhere on the stripe, the fluxes will repel, and we get a concentration of flux lines around the S-S interface. (The same as with N-N interface.) Encoding consists of creating S-S and N-N interfaces, and reading consists of (you guessed it) detecting them. The S-S and N-N interfaces are called flux reversals.

The external magnetic field used to flip the polarities is produced by a solenoid, which can reverse its polarity by reversing the direction of current. An encoding head solenoid looks like a bar magnet, bent into the shape of a ring so that the north/south poles are very close and face each other across a tiny gap. The field of the solenoid is concentrated across this gap, and when elemental magnetic particles of the magstripe are exposed to this field, they polarize to the opposite. (That is, unlike poles attract.). Movement of the stripe past the solenoid gap during which the polarity of the solenoid is reversed will produce a single flux reversal. To erase a magstripe, the encoding head is held at a constant polarity and the entire stripe is moved past it. If you don't lay down any flux reversals, then you encode no data.

So, we now know that flux reversals are only created the instant the solenoid changes its polarity. If the solenoid were to remain at its current polarity, no further flux reversals would be created as the magstripe moves across the head from right to left. But, if we were to change the solenoid gap polarity from N-S to S-N, then (you guessed it) a N-N flux reversal would instantly be created. Just remember, for each and every reversal in solenoid polarity, a single flux reversal is created. An encoded magstripe is therefore just a series of flux reversals - N-N followed by S-S followed by N-N...etc.

How the heck are flux reversals read and interpreted as data? Another solenoid called a read head is used to detect these flux reversals. The read head operates on the principle of electromagnetic reciprocity: current passing through a solenoid produces a magnetic field at the gap. Therefore, the presence of a magnetic field at the gap of a solenoid coil will produce a current in the coil! The strongest magnetic fields on a magstripe are at the points of flux reversals. These are detected as voltage peaks by the reader, with +/- voltages corresponding to N-N/S-S flux reversals. (Remember, flux reversals come in 2 flavours.) The 'peak readout' square waveform is critical. Note that voltage peaks remain the same until a new flux reversal is encountered further along the stripe.

Now, how can we encode data? The most common technique used is known as Aiken Biphase, or "two-frequency coherent-phase encoding." (Sounds impressive, eh?).

There you have it. Data is encoded in "bit cells", the frequency of which is the frequency of '0' signals. '1' signals are exactly twice the frequency of '0' signals.

Therefore, while the actual frequency of the data passing the read head will vary due to swipe speed, data density, etc, the '1' frequency will always be twice the '0' frequency.

## Standards

Now, we're all familiar with binary and how numbers and letters can be represented in binary fashion very easily. There are obviously an infinite number of possible standards, but thankfully the American National Standards Institute (ANSI) and the International Standards Organization (ISO) have chosen 2 standards.

### The ANSI/ISO BCD Data Format

Note: This format is used on Track 2 of magstripes encoded in the standardized scheme.

This is a 5-bit Binary Coded Decimal format. It uses a 16-character set, which uses 4 of the 5 available bits. The 5th bit is an odd parity bit, which means there must be an odd number of 1's in the 5-bit character. The parity bit will 'force' the total to be odd. Also, the Least Significant Bits are read first on the strip.

The sum of the 1's in each case is odd, thanks to the parity bit. If the read system adds up the 5 bits and gets an even number, it flags the read as error, and you've got to scan the card again. (Yes, we know a lot of you out there already understand parity, but we must cover all the bases...not everyone sleeps with their modem.)

Remember that b1 (bit #1) is the LSB (least significant bit)! The LSB is read first!

Hexadecimal conversions of the Data Bits are given in parenthesis (xH).

| Data Bits | | | | Parity | | | |
|---|---|---|---|---|---|---|---|
| b1 | b2 | b3 | b4 | b5 | Char. | Hex | Function |
| 0 | 0 | 0 | 0 | 1 | 0 | 0H | Data |
| 1 | 0 | 0 | 0 | 0 | 1 | 1H | Data |
| 0 | 1 | 0 | 0 | 0 | 2 | 2H | Data |
| 1 | 1 | 0 | 0 | 1 | 3 | 3H | Data |
| 0 | 0 | 1 | 0 | 0 | 4 | 4H | Data |
| 1 | 0 | 1 | 0 | 1 | 5 | 5H | Data |
| 0 | 1 | 1 | 0 | 1 | 6 | 6H | Data |
| 1 | 1 | 1 | 0 | 0 | 7 | 7H | Data |
| 0 | 0 | 0 | 1 | 0 | 8 | 8H | Data |
| 1 | 0 | 0 | 1 | 1 | 9 | 9H | Data |
| 0 | 1 | 0 | 1 | 1 | : | AH | Control |
| 1 | 1 | 0 | 1 | 0 | ; | BH | Start Sentinel |
| 0 | 0 | 1 | 1 | 1 | < | CH | Control |
| 1 | 0 | 1 | 1 | 0 | = | DH | Field Separator |
| 0 | 1 | 1 | 1 | 0 | > | EH | Control |
| 1 | 1 | 1 | 1 | 1 | ? | FH | End Sentinel |

Summation: 16 Character 5-bit Set. 10 Numeric Data Characters. 3 Framing/Field Characters. 3 Control Characters

The magstripe begins with a string of zero bit-cells to permit the self-clocking feature of biphase to "sync" and begin decoding. A "Start Sentinel" character then tells the reformatting process where to start, grouping the decoded bitstream into groups of 5 bits each. At the end of the data, an "End Sentinel" is encountered, which is followed by a "Longitudinal Redundancy Check" (LRC) character. The LRC is a parity check for the sums of all b1, b2, b3, and b4 data bits of all preceding characters. The LRC character will catch the remote error that could occur if an individual character had two compensating errors in its bit pattern (which would fool the 5th-bit parity check).

The Start Sentinel, End Sentinel, and LRC are collectively called "Framing Characters", and are discarded at the end of the reformatting process.

**ANSI/ISO ALPHA Data Format**

Note: This format is used on Track 2 of magstripes encoded in the standardized scheme.

The second ANSI/ISO data format is alphanumeric and involves a 7-bit character set with 64 characters. As before, an odd parity bit is added to the required 6 data bits for each of the 64 characters.

Remember that b1 (bit #1) is the LSB (least significant bit)! The LSB is read first! Hexadecimal conversions of the Data Bits are given in parenthesis (xH).

| Data Bits | | | | | Parity | | | | |
|---|---|---|---|---|---|---|---|---|---|
| b1 | b2 | b3 | b4 | b5 | b6 | b7 | Character | Hex | Function |
| 0 | 0 | 0 | 0 | 0 | 0 | 1 | space | | |
| 1 | 0 | 0 | 0 | 0 | 0 | 0 | ! | | |
| 0 | 1 | 0 | 0 | 0 | 0 | 0 | " | | |
| 1 | 1 | 0 | 0 | 0 | 0 | 1 | # | | |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| 0 | 0 | 1 | 0 | 0 | 0 | 0 | $ | (4H) | " |
| 1 | 0 | 1 | 0 | 0 | 0 | 1 | % | (5H) | Start Sentinel |
| 0 | 1 | 1 | 0 | 0 | 0 | 1 | & | (6H) | Special |
| 1 | 1 | 1 | 0 | 0 | 0 | 0 | ' | (7H) | " |
| 0 | 0 | 0 | 1 | 0 | 0 | 0 | | (8H) | " |
| 1 | 0 | 0 | 1 | 0 | 0 | 1 | ) | (9H) | " |
| 0 | 1 | 0 | 1 | 0 | 0 | 1 | * | (AH) | " |
| 1 | 1 | 0 | 1 | 0 | 0 | 0 | + | (BH) | " |
| 0 | 0 | 1 | 1 | 0 | 0 | 1 | , | (CH) | " |
| 1 | 0 | 1 | 1 | 0 | 0 | 0 | - | (DH) | " |
| 0 | 1 | 1 | 1 | 0 | 0 | 0 | . | (EH) | " |
| 1 | 1 | 1 | 1 | 0 | 0 | 1 | / | (FH) | " |
| 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | (10H) | Data (numeric) |
| 1 | 0 | 0 | 0 | 1 | 0 | 1 | 1 | (11H) | " |
| 0 | 1 | 0 | 0 | 1 | 0 | 1 | 2 | (12H) | " |
| 1 | 1 | 0 | 0 | 1 | 0 | 0 | 3 | (13H) | " |
| 0 | 0 | 1 | 0 | 1 | 0 | 1 | 4 | (14H) | " |
| 1 | 0 | 1 | 0 | 1 | 0 | 0 | 5 | (15H) | " |
| 0 | 1 | 1 | 0 | 1 | 0 | 0 | 6 | (16H) | " |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 1 | 1 | 0 | 1 | 0 | 1 | 7 | (17H) | " |
| 0 | 0 | 0 | 1 | 1 | 0 | 1 | 8 | (18H) | " |
| 1 | 0 | 0 | 1 | 1 | 0 | 0 | 9 | (19H) | " |
| 0 | 1 | 0 | 1 | 1 | 0 | 0 | : | (1AH) | Special |
| 1 | 1 | 0 | 1 | 1 | 0 | 1 | ; | (1BH) | " |
| 0 | 0 | 1 | 1 | 1 | 0 | 0 | < | (1CH) | " |
| 1 | 0 | 1 | 1 | 1 | 0 | 1 | = | (1DH) | " |
| 0 | 1 | 1 | 1 | 1 | 0 | 1 | > | (1EH) | " |
| 1 | 1 | 1 | 1 | 1 | 0 | 0 | ? | (1FH) | End Sentinel |
| 0 | 0 | 0 | 0 | 0 | 1 | 0 | @ | (20H) | Special |
| 1 | 0 | 0 | 0 | 0 | 1 | 1 | A | (21H) | Data (alpha) |
| 0 | 1 | 0 | 0 | 0 | 1 | 1 | B | (22H) | " |
| 1 | 1 | 0 | 0 | 0 | 1 | 0 | C | (23H) | " |
| 0 | 0 | 1 | 0 | 0 | 1 | 1 | D | (24H) | " |
| 1 | 0 | 1 | 0 | 0 | 1 | 0 | E | (25H) | " |
| 0 | 1 | 1 | 0 | 0 | 1 | 0 | F | (26H) | " |
| 1 | 1 | 1 | 0 | 0 | 1 | 1 | G | (27H) | " |
| 0 | 0 | 0 | 1 | 0 | 1 | 1 | H | (28H) | " |
| 1 | 0 | 0 | 1 | 0 | 1 | 0 | I | (29H) | " |
| 0 | 1 | 0 | 1 | 0 | 1 | 0 | J | (2AH) | " |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 1 | 0 | 1 | 0 | 1 | 1 | K | (2BH) | " |
| 0 | 0 | 1 | 1 | 0 | 1 | 0 | L | (2CH) | " |
| 1 | 0 | 1 | 1 | 0 | 1 | 1 | M | (2DH) | " |
| 0 | 1 | 1 | 1 | 0 | 1 | 1 | N | (2EH) | " |
| 1 | 1 | 1 | 1 | 0 | 1 | 0 | O | (2FH) | " |
| 0 | 0 | 0 | 0 | 1 | 1 | 1 | P | (30H) | " |
| 1 | 0 | 0 | 0 | 1 | 1 | 0 | Q | (31H) | " |
| 0 | 1 | 0 | 0 | 1 | 1 | 0 | R | (32H) | " |
| 1 | 1 | 0 | 0 | 1 | 1 | 1 | S | (33H) | " |
| 0 | 0 | 1 | 0 | 1 | 1 | 0 | T | (34H) | " |
| 1 | 0 | 1 | 0 | 1 | 1 | 1 | U | (35H) | " |
| 0 | 1 | 1 | 0 | 1 | 1 | 1 | V | (36H) | " |
| 1 | 1 | 1 | 0 | 1 | 1 | 0 | W | (37H) | " |
| 0 | 0 | 0 | 1 | 1 | 1 | 0 | X | (38H) | " |
| 1 | 0 | 0 | 1 | 1 | 1 | 1 | Y | (39H) | " |
| 0 | 1 | 0 | 1 | 1 | 1 | 1 | Z | (3AH) | " |
| 1 | 1 | 0 | 1 | 1 | 1 | 0 | [ | (3BH) | Special |
| 0 | 0 | 1 | 1 | 1 | 1 | 1 | \ | (3DH) | Special |
| 1 | 0 | 1 | 1 | 1 | 1 | 0 | ] | (3EH) | Special |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| 0 | 1 | 1 | 1 | 1 | 1 | 0 | ^ | (3FH) | Field Separator |
| 1 | 1 | 1 | 1 | 1 | 1 | 1 | _ | (40H) | Special |

Summation: 64 Character 7-bit Set. 43 Alphanumeric Data Characters. 3 Framing/Field Characters. 18 Control/Special Characters

## Tracks

Now we know how the data is stored. But where is the data stored on the magstripe? ANSI/ISO standards define three tracks, each of which is used for different purposes. These tracks are defined only by their location on the magstripe, since the magstripe as a whole is magnetically homogeneous.

There is, by specification, an exact distances of each track from the edge of the card, as well as the uniform width and spacing. Place a magstripe card in front of you with the magstripe visible at the bottom of the card. Data is encoded from left to right. (Just like reading a book, eh?).

**ANSI/ISO Track 1,2,3 Standards**

| Track | Name | Density | Format | Characters | Function |
|---|---|---|---|---|---|
| 1 | IATA | 210 bpi | ALPHA | 79 | Name & Account |
| 2 | ABA | 75 bpi | BCD | 40 | Account |
| 3 | THRIFT | 210 bpi | BCD | 107 | Account & Encode Transaction |

**Track 1 Layout**

| SS | FC | PAN | Name | FS | Additional Data | ES | LRC |

SS = Start Sentinel "%"
FC = Format Code

PAN = Primary Acct. # (19 digits max)
FS = Field Separator "^"
Name = 26 alphanumeric characters max.
Additional Data = Expiration Date, offset, encrypted PIN, etc.
ES = End Sentinel "?"
LRC = Longitudinal Redundancy Check

**Track 2 Layout**

| SS | PAN | FS | Additional Data | ES | LRC |

SS = Start Sentinel ";"
PAN = Primary Acct. # (19 digits max)
FS = Field Separator " = "
Additional Data = Expiration Date, offset, encrypted PIN, etc.
ES = End Sentinel "?"
LRC = Longitudinal Redundancy Check

**Track 3 Layout**

Since Track 3 is somewhat "non-standard" so the only thing that can be stated here is that it’s similar to Tracks 1 and 2 and that it’s generally numeric data only.

Track 2, "American Banking Association," (ABA) is most commonly used. This is the track that is read by ATMs and credit card checkers. The ABA designed the specifications of this track and all world banks must abide by it. It contains the cardholder's account number, encrypted PIN, plus other discretionary data.

Track 1, named after the "International Air Transport Association," contains the cardholder's name as well as account and other discretionary data. This track is sometimes used by the airlines when securing reservations with a credit card; your name just "pops up" on their machine when they swipe your card!

Track 3 is unique. It was intended to have data read and written on it. Cardholders would have account information updated right on the magstripe. Unfortunately, Track 3 is pretty much an orphaned standard. Its original design was to control off-line ATM transactions, but since ATMs are now on-line all the time, it's pretty much useless. Plus the fact that retailers and banks would have to install new card readers to read that track, and that costs $$.

**Magstripe Coercivity**

Magstripes themselves come in different flavours. The coercivity of the magnetic media must be specified. The coercivity is the magnetic field strength required to demagnetize an encoded stripe, and therefore determines the encode head field strength required to encode the stripe. A range of media coercivities are available ranging from 300 Oersteds (Oe) to 4,000 Oe. That boils down to high-energy magstripes (4,000 Oe) and low-energy magstripes (300 Oe). These are also known, in industry parlance as, "HiCo" and "LoCo."

Remember: since all magstripes have the same magnetic properties, regardless of their coercivity, readers cannot tell the difference between high and low energy stripes. Therefore, both HiCo and LoCo stripes are read the same by the same readers.

Low-energy media is most common. It is used on all financial cards, but its disadvantage is that it is subject to accidental demagnetization from contact with common magnets (refrigerator, TV magnetic fields, etc.).

High-energy media is used for ID Badges and access control cards, which are commonly used in 'hostile' environments (worn on uniform, used in stockrooms). Normal magnets will not affect these cards, and low-energy encoders cannot write to them.